LOW COST ELECTROCARDIOGRAM SYSTEM BASED ON MOBILE PLATFORMS FOR TELEMEDICINE APPLICATIONS

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Abstract-**The majority of cardiovascular diseases cases occurs in low and middle income countries. Even at high-income countries, heart diseases demands great economic resources. In this way, this work proposes a low-cost telemedicine application to collect, transmit and display ECG exam for cardiologists. To reduce the final cost, the system proposed here employs a data acquisition board based on basic microcontroller, a low-cost PDA equipment with infrared interface and open source software. Coasting 76% less than the revised commercial and academic equipments, this system achieves or even surpasses their performance in resolution and signal quality.**
***Keywords* – EGC, Portable, Low Cost, Telemedicine**

I. INTRODUCTION

In the 1990's, 85% of the cardiovascular diseases arose from low-income and middle-income countries and such pattern should not change until 2020 [1]. Indeed, the relationship between the rise of cardiovascular diseases and the socioeconomic status has already been analyzed in [2] through the association of the mortality rate and the per capita income in the city of Rio Janeiro – Brazil. This work has shown that between the years of 1980 and 2004 the mortality rate for cardiovascular diseases fall down from 200 to 100 deaths for each 100.000 habitants whilst the per capita income increased from 1000 to 3000 dollars.

On the other hand, cardiovascular diseases are still the main cause of death at high-income countries. For instance, in the United States, heart diseases killed 900.000 Americans in 2003 (last data available). This number accounted for 37% of all deaths that year according to the American Heart Association [3]. The statistics of American Heart Society also shows that the cost for healthcare services of cardiovascular diseases for the year of 2006 is estimated at $403 billion.

The two clinical pictures mentioned above highlight the fact that healthcare of cardiovascular diseases must be in concern when talking about service coast-effectiveness. This concern might be even greater should the service be made at isolated regions such as rural areas. Actually, those areas demand more investments on communication, approach and professional training for face-to-face care.

In spite of this, in the 1970s, the term Telemedicine appeared describing the use of telecommunication and information technology to aid prevention, diagnosis and disease treatment at isolated regions [4]. For instance, portable electrocardiograph systems are important examples of telemedicine applications for medical care of cardiovascular diseases. The HeartView system from Aerotel Medical Systems [5], for example, is one of the most used portable system for collect, transmit and diagnosis the ECG records. However, HeartView still has low resolution performance, common mode reject ratio (CMRR) and sampling frequency. Systems that allow to store-and-forward patient exams from a small health center to the cardiologist are another type of telemedicine application. For instance, a digital system for electrocardiogram transmission via modem connection has been implemented at two small cities of the Southern Brazil and improved the quality of the healthcare services as described in [6]. However, such project does not aim for cost-effectiveness in the first place, once it is not based on open software technologies.

The purpose of this work is therefore to develop a portable ECG platform based on low cost technologies such as basic microcontroller, PDA equipment and open source software.

II. METHODS

The proposed system consists of three parts – an ECG data acquisition board based on a PIC microcontroller; a PalmOS software integrated on a PDA to gather and register patients data; and finally, PC software developed for specialized medical analysis and exam printing, as shown in Fig. 1.

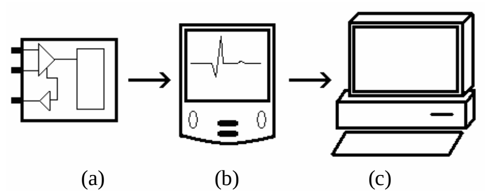

Fig. 1. ECG system - (a) data aquisition board, (b) PDA, (c) PC´s Sofware.

A. Acquisition Board

The acquisition board is composed of a conditioning circuit connected to a PIC microcontroller. The communication with the PDA is established through infrared by means of an infrared transceiver.

The amplification and filtering circuit is shown in Fig. 2. This circuit was inspired in similar works such as [7, 8] and is based on the AD623 instrumentation amplifier from Analog Devices. This amplifier has as key features low cost and low power consumption. The AD623 has a CMRR greater than 100 dB within the range of 1 up to 60 Hz. The amplification gain G_1 given by (1) was adjusted to 10 so as to avoid the saturation effect caused by the DC level of the input that is introduced by the electrodes. The DC level is called ECG baseline which has the common value of 300 mV.

$$R_1 + R_2 = 100\text{K}\Omega\,(G_1 - 1) \qquad (1).$$

Filtering is performed by a first-order high-pass filter. The cutoff frequency of this filter is around 0.5 Hz which is the standard value for clinic ECG [8]. The high-pass filtering aims to reduce the variance at the DC level of the input and is given by:

$$f_1 = 1/(2\pi R_5 C_3) \qquad (2).$$

Soon after, a first-order low-pass filter is utilized to restrict the spectral content to the Nyquist frequency:

$$f_2 = 1/(2\pi R_3 C_1) \qquad (3).$$

The filter gain is given by (4) and it is adjusted to 50, totalizing an amplification circuit gain of 500. The operational amplifier employed in these filters is the OPA4344 from BurrBrow, which has a rail-to-rail output, besides the low cost, low noise and low consumption.

$$G_2 = R_3/R_4 \qquad (4).$$

The microcontroller is the subsequent block just after the amplifier. It comprises all of the remaining functions of the data acquisition board as A/D conversion and signal transmission through IrDA [9]. Fig. 3 shows the schematic diagram of this block which is composed of a microcontroller from Microchip Inc. The model number of the microcontroller employed here is the PIC16C733. This microcontroller is running at its standard configuration in association with an optic device for infrared communication.

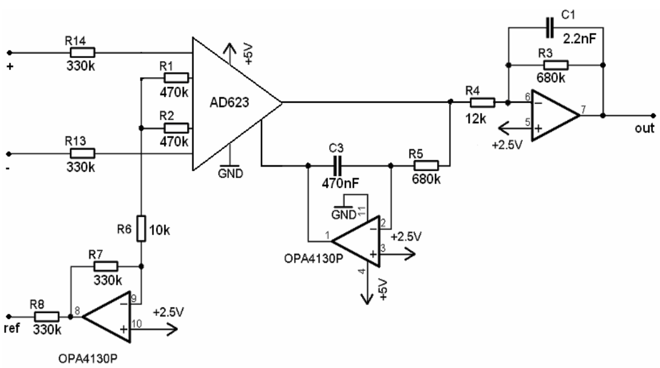

Fig. 2. ECG continiong circuit.

The microcontroller has as main features an A/D converter of 12 bits, low consumption and low cost.

The microcontroller program was written in C standard and works using only two hardware interruptions. These interruptions are supplied by the PIC. The first one is the serial reception of some value in the port USART and second one is the overflow of the counter Timer1.

The program flowchart is shown in Fig. 4. The working principle is simple: The PIC starts waiting for the interruption signal from the serial reception. This signal notifies the exam duration, that is, how many samples should be read for the chosen sampling time. The serial reception interruption enables the Timer1 interruption and turns itself off. The counter is configured to count to 3.2 ms, which is the sampling time. When the counter reaches this limit, the Timer1 routine is activated. This routine reads the current sample values at the output of the A/D converter. This data is then sent to the PDA through infrared communication using the IrComm protocol from IrDA specification [9]. The Timer1 interruption is disabled when all of samples were sent, and once that occurs, the serial reception interruption is enabled again.

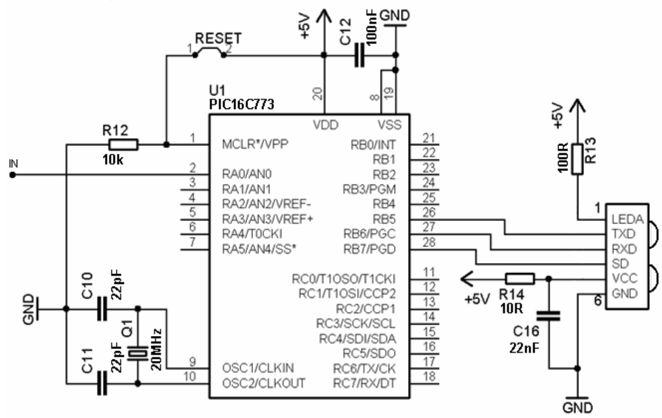

Fig. 3. Microcontroller

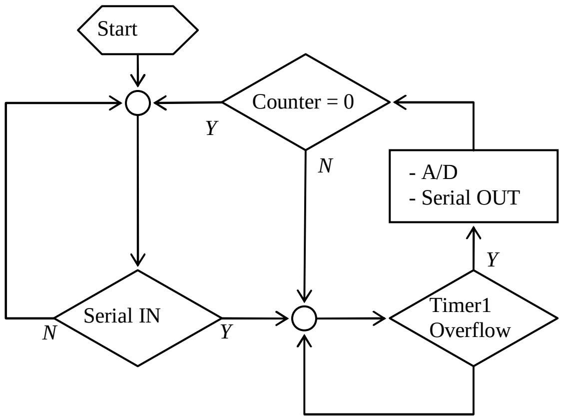

Fig. 4. Flowchart of the microcontroller software.

B. PDA Software.

To collect the ECG signal and manage the patient records, a simple software was developed in HandeldBasic++ [10], which is a powerful tool to PalmOS software design. Among the HandeldBasic attributes are the easy programming and the capacity to generate small and fast executables.

The characteristics of the PDA software are exhibited in Fig. 5. The interface is composed of a menu and two tabs. The menu has three options: New registration, Clear register and Preferences. The first tab shows all the patients registered at the database. The second tab allows the health agent to collect and choose the type of derivation of the ECG signal acquired from the patient. Once one selects a patient in the first tab, the second tab opens asking about the type of the derivation, so that collecting process can be started.

The ECG signal collected through the second tab is then stored in binary files which contains the information of each

patient and its derivation. After the collect, the files are transmitted through ftp or e-mail to the internet server at the health center to posterior medical analysis and printing.

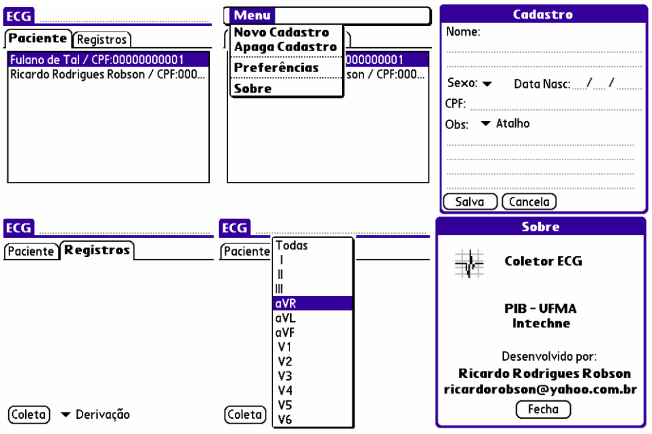

Fig. 5. PDA sofware in portuguese.

C. PC Software

The PC software functionality is just to exhibit and print the ECG exam. This program was written and compiled in Matlab for native execution and allows the opening and visualization of files which were sent to the server. Since it was written in Matlab, it can be modified to the majority of platforms, as for instance, Linux , Windows and Mac.

Fig. 6 shows the PC software screen-shots displaying an ECG exam collected for test and allows the user to print or forward the exam to the cardiologist for diagnosis.

III. Results and Discussion

The analysis of the system performance is shown in Table 1, which compares system features such as resolution and cost of licensing/implementation with two other ECG systems. The first column shows the characteristics of the commercial equipment [5]; the second one shows the academic project implemented in the Southern Brazil [6]; The proprieties of this work are shown in the third column.

The system proposed here employs an A/D converter of 12 bits getting a wide advantage at resolution and signal quality in relation to the HeartView system which has only eight bits of resolution. Furthermore, the HeartView acquires the ECG signal with only half of the sampling frequency available on this project. It must be notified that HeartView system is not an open project and despite its low quality features, it still is widely used due its audio interface which transmits the signal through the phone line. This is a significant feature once that does not require an internet connection to transmit the collected ECG record.

The academic work implemented in Southern Brazil transmits the ECG signal from the health center to a remote cardiologist. However, it requires a mobile call which is far more expansive than a fixed phone call. Besides that fact, that system employs a laptop computer for remotely diagnosis and software that require licensing which increases the cost of the project. Contrarily, this work is based on low cost PDA equipment and open source software which allows mobility and reduces the final cost, respectively.

IV. Conclusion

In this work, a low-cost portable electrocardiogram system has been described. First, the ECG signal is collected through the data acquisition board which is based on a PIC microcontroller. Then, the ECG record is sent to the PDA equipment by infrared communication. The PDA software allows the health agent to save the record from each derivation independently and to observe whether there is some error with the acquisition or not. Afterwards, the PDA

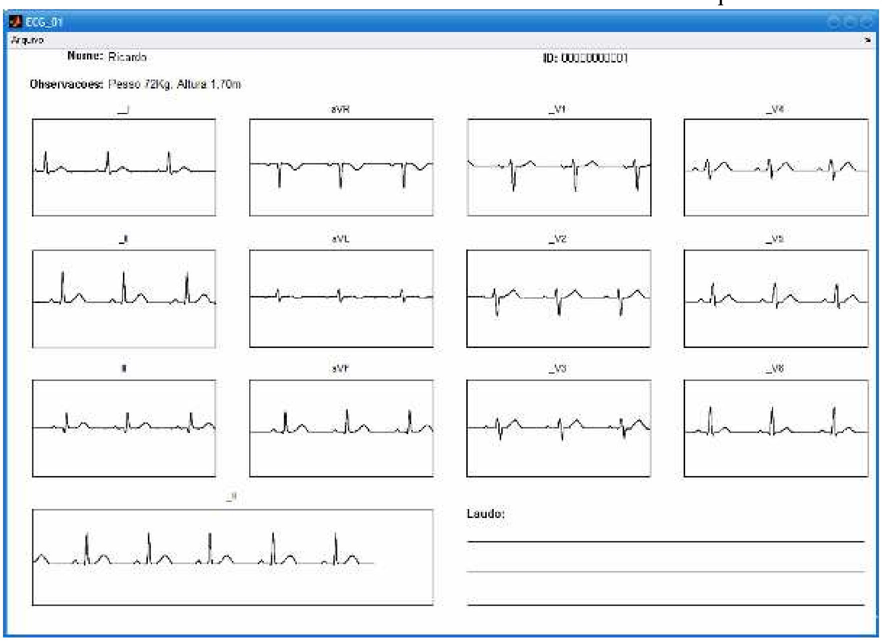

Fig. 6. PC software for analysis and printing.

sends the information through the internet to the health center server. Finally, the exams can be analyzed by a cardiologist through the PC software. This system was designed with high quality features achieving or even surpassing the performance of the revised academic and commercial equipment. However, the estimated cost for the system proposed here is smaller than other ones.

TABLE I
ANALYSIS OF THE SYSTEM FEATURES

	HeartView	Sparenberg et al	This Project
Input Impedance	10 M	n/a	20 M
CMRR	40-80 dB	112 dB	102 dB
Record Time	5 seg	10 seg	10 seg
Numbers of Exams	2	n/a	40 (2Mb)
Sampling Rate	150 Hz	300 Hz	312 Hz
Resolution	8 bits	12 bits	12 bits
Transmition method	Fixed phone call	Mobile cal / internet	Internet
Mobility	Yes	No	Yes
Cost (US$)	-	3500	850

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